

Realistic Simulation of the MAPS Response

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The MAPS technology is considered as a possible choice for the ILC Vertex Detector. Test results of MIMOSA-5 sensors indicate that the pixel multiplicity and the single point resolution depend significantly on the incident particle angle. We propose a simple model describing charge distribution in the detector, which can be used for detailed simulation of the Vertex Detector response. Good agreement with beam test data is obtained. A new class for Track Detailed Simulation (TDS) has been developed and implemented in the EU Telescope software framework.

1 Introduction

The optimisation of the design of the Vertex Detector (VXD) for the experiment at the International Linear Collider (ILC) is based on the Monte Carlo (MC) studies. In order to achieve a realistic description of the VXD performances a detailed MC simulation is required. Simulation studies performed so far focused mainly on the detector geometry, assuming a given resolution of the pixel sensor. However, dedicated studies show that the pixel multiplicity and the single point resolution depend significantly on the angle of the incident particle. Thus a Monte Carlo simulations should be supplemented by a digitisation procedure describing detector response to charged particles on the pixel level. This was the motivation for developing a model of signal formation for the Monolithic Active Pixel Sensor (MAPS) [2] which could be used in the full simulation of the Vertex Detector.

2 Tests of the MAPS detectors

The MAPS technology provides a very good spatial resolution, high signal to noise ratio, low material budget, low costs of fabrication and high radiation tolerance. The Warsaw/Lodz group is involved in studies of the MAPS tracking performances and signal formation. Two MAPS detectors have been investigated: MIMOSA-5 with 17 μm pixel pitch and MIMOSA-18 with 10 μm pixel pitch, both with the epitaxial layer of 14 μm . The sensors have been exposed to the 6 GeV electron at DESY and oriented at different angles w.r.t. the beam direction. An average cluster shape for MIMOSA-5, as measured for electrons incident at $\theta = 75^\circ$ is shown in fig. 1(left). The elongation of the clusters is clearly visible. The dependence of the number of pixels (with signal to noise ratio grater than three) on the track inclination is shown in fig. 1(right).

The increase of pixel multiplicity with the θ angle will influence the VXD tracking performances and detector occupancy. This has to be taken in to account in development of clustering algorithms and in the single point resolution estimates.

*Supported from the research funds of the Polish Ministry of Science and Higher Education as a part of the research project.

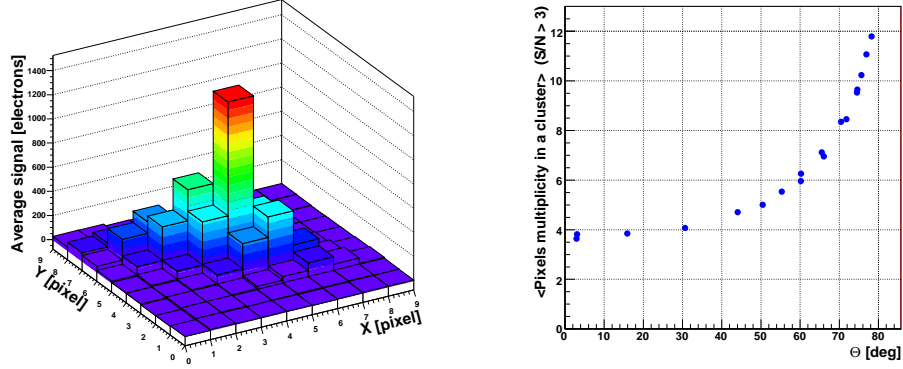


Figure 1: Results of the MIMOSA-5 tests with 6 GeV electron beam: average cluster shape for beam incident angle $\theta = 75^\circ$ (left) and the mean pixel multiplicity in the cluster as a function of the track inclination θ (right).

3 Simple model of charge diffusion

There are three main layers of the MAPS device: a substrate, an epitaxial layer and a pixel layer, see fig. 2. A charged particle traversing the detector ionise the silicon. In the proposed digitisation model for the MAPS detector three major effects influence charge distribution. First, it is assumed that the charge generated in the epitaxial layer diffuses isotropically. This means that charge carriers propagate in all directions with the same probability. Approximately 50% of carriers move directly toward collecting diodes and the other 50% towards the substrate. We assume that after reaching the substrate the carriers are reflected due to the potential barrier present as an effect of a different doping concentration of the substrate and the epitaxial layer, and that the reflection angle is equal to the angle of incidence. Finally, we assume that the charge reaching the collecting diodes is smaller than the primary ionization due to the trapping of the carriers in the silicon. This simple model provides a good description of charge sharing in the MAPS device for all incident angles, assuming the charge attenuation length of about $50 \mu m$.

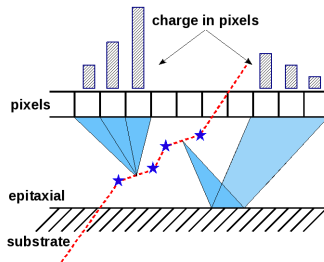


Figure 2: Schematic cross-section of the MAPS detector.

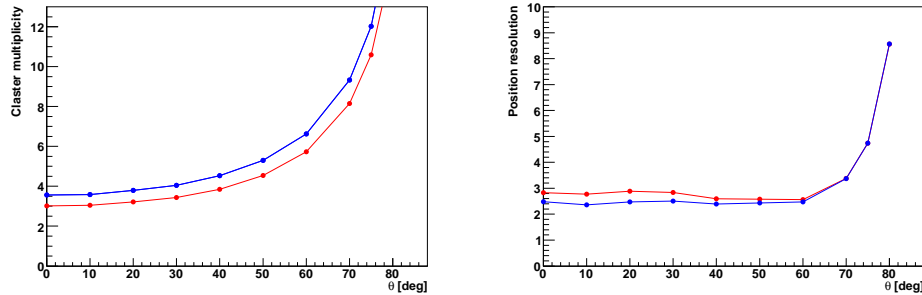


Figure 3: First results of the MIMOSA-5 simulation with the TDS package: mean cluster multiplicity for 6 GeV electrons (left) and the estimated position resolution (right) as a function of the incident particle angle.

4 Implementation in the ILC Software

Particles crossing at large angles can scatter inside the sensor resulting in the increased ionisation path. This is properly modelled in Geant. However, Mokka used to add all Geant steps in given layer and store only single hit per particle, with total path length and energy deposit. This made realistic simulation of the detector response impossible. Therefore a dedicated option has been implemented in new Mokka release, which forces Mokka to store separate Geant steps. It is currently implemented for VXD only, but can be extended to other detectors if required. For high energy particles from interaction point new option increases average number of VXD hits generated by Mokka by about 25%. At the same time the number of hits with very large energy deposit (above 10 mips) is suppressed by over an order of magnitude.

A new class for Track Detailed Simulation (TDS) has been developed and implemented in the ILC software framework within the EUTelescope package. For each Mokka hit, the charge deposit is divided into many steps along particle path. Charge collected in each pixel is then calculated by numerical integration of the charge diffusion formula. Integration results are stored in a dedicated grid, so simulation is very fast (except for first 100 hits). After the collected charge is calculated, gain, noise and analog to digital conversion are taken into account. Work is in progress to extend TDS package to the VXD detector simulation.

First, preliminary results of the MIMOSA-5 simulation with the TDS package are presented in fig. 3. Shown in the mean cluster multiplicity for 6 GeV electrons, as a function of the incident particle angle, and the estimated position resolution from center-of-gravity of 3x3 cluster around pixel with maximum charge. Two sets of results (indicated by blue and red lines) correspond to different digitization parameters assumed.

References

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- [2] G. Deptuch *et al.*, Nucl. Instr. and Meth. Phys. Res. **A511** 240 (2003).